BHCal Software Priorities | Main Thrusts (1/3)

I. Support test-stand/beam studies & increasing realism in simulation

1) **Complete RCDAQ2JANA proof-of-concept** (in progress here)
   - ☑ Generate random hits and save them to an output tree via PODIO **[done!]**
   - b) Process saved random hits in EICrecon via a plugin
   - c) Get pmonitor to run in EIC shell
   - d) Create hits from saHCal data via pmonitor and save them to an output PODIO tree
   - e) Process saved saHCal hits in EICrecon via a plugin
2) **Increasing realism of digitization in simulation**
   - – Largely being driven by BIC & LFHCAL teams
   - – See update in software meeting here
   - ☞ Will need someone to implement HGCROC digitization chain in BHCal plugin once ready

BHCal Software Priorities | Main Thrusts (2/3)

II. Complete TDR Analyses, i.e. demonstrate BHCal can do the physics we say it can

1) **Fix misplaced tiles** [epic#829]
   - ☞ Highest priority!!
2) After fixing, recreate **all** BHCal pTDR plots
3) Finish manual calibration (see later slide)
   - ☞ Necessary for following items!
4) **Event reconstruction studies:**
   - › EtMiss (fig. 8.195)
   - › JB variables (fig. 8.194)
5) **Jet reconstruction:**
   - › Jet charged/neutral fraction vs. eta (fig. 8.177)
   - › Jet spectra for full jets (track+EMCal+HCal)
   - › JES/R for full jets (fig.s 8.196, 8.178)

What physics does the BHCal address?

- Constraining the JES/R via the neutral component of jets
- CC DIS event tagging
- Jacquet-Blondel Kinematics
- Muon identification (talk to Jihee Kim)
- (Neutron reconstruction)

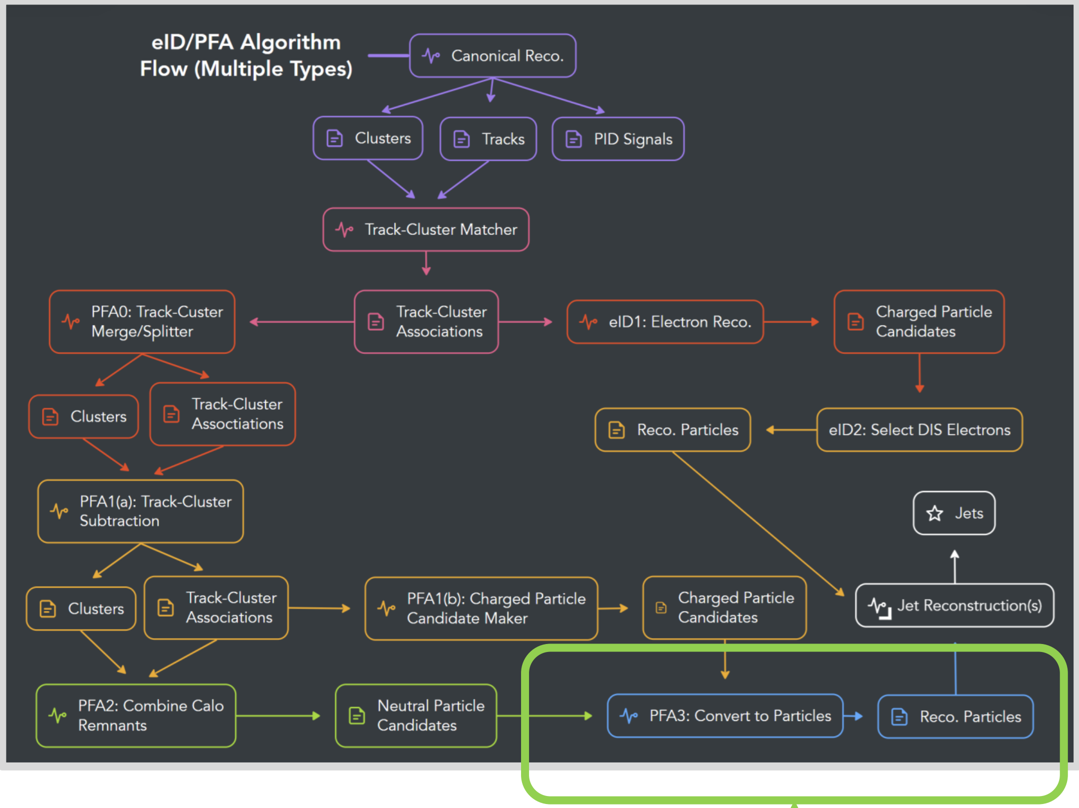
Additional cross-checks to do

- Before fixing tiles, rerun BHCal-only resolution calculation using only eta < 0
  - ☞ To confirm impact of hole
- Rerun ML calibration using (1) split/merge clusters, and (2) sum of clusters
  - ☞ To better understand impact of cluster splitting/clustering inefficiencies

BHCal Software Priorities | Main Thrusts (3/3)

III. Integrate ML calibration into EICrecon

1) Update training script to
   a) Use *cluster-truth associations* rather than single particle events
   b) Train model using full 4-vector as target
   c) Process *edm4eic::Tensor* objects as inputs, outputs
2) Re-optimize (if needed) on realistic event topologies
3) Implement EICrecon tooling
   1) **Pre-ML algorithm:** packs cluster information into input *edm4eic::Tensor* objects
   2) **Inference algorithm:** deploys model via ORT
   3) **Post-ML algorithm:** unpacks output *edm4eic::Tensor* objects into particle information
4) Compare against baseline (manual) PFA regressions



Model will be deployed HERE in PF chain initially

BHCal Software Priorities | Manual Calibration

Manual Calibration: idea is to use single particle to get relative scale of EMCal & HCal:

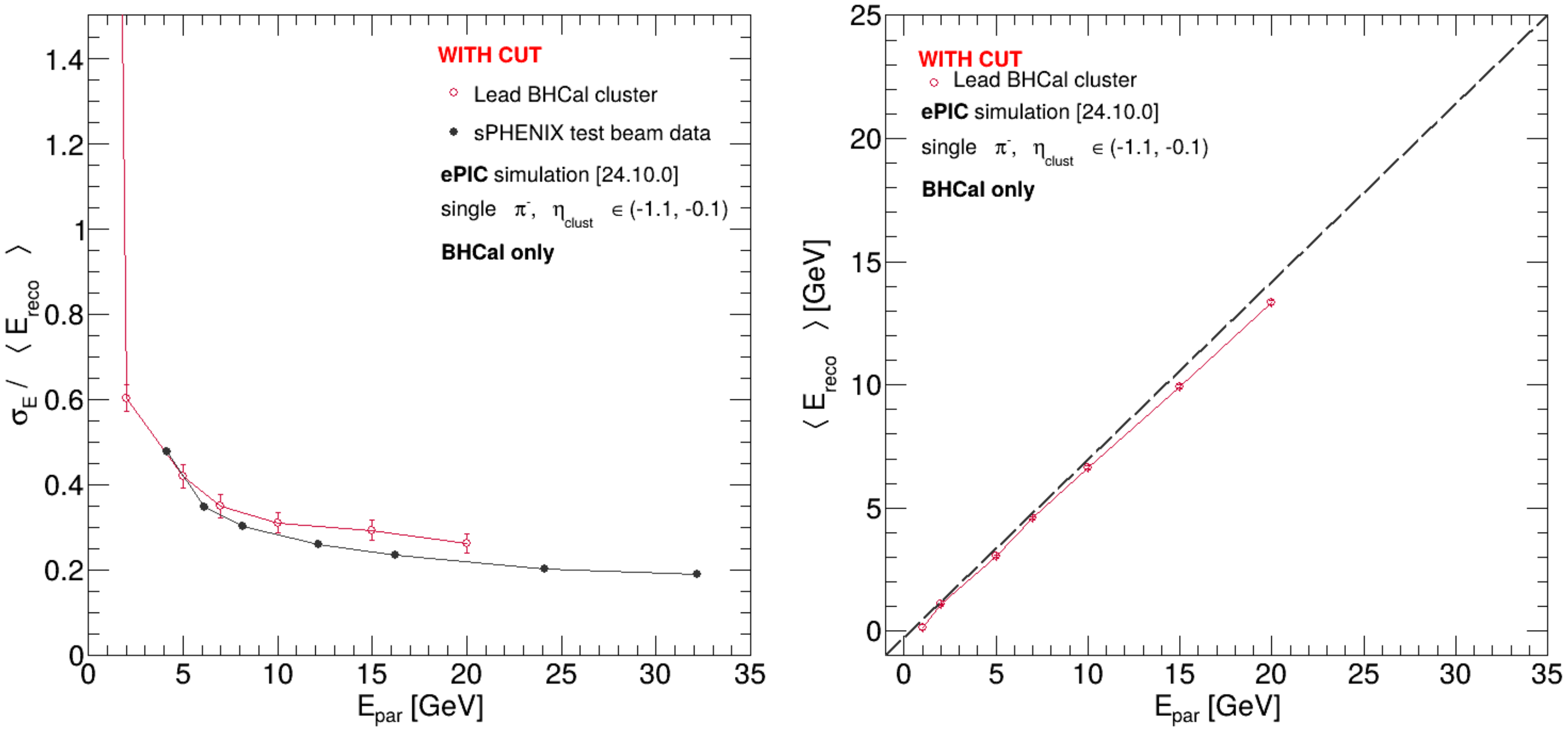
[1] $E_{calib} = A(E_{em} + E_h)$
[2] $E_{calib} = A(E_{em} + BE_h)$

- Wanted to check 3 methods of getting manual calibrations
  1) **Naïve method:** plot ratio of $(E_{em} + E_h)/E_{par}$, set A in equation [1] to 1/mean of distribution
     - Very easy to do, and very obviously not good
     - Just want bare minimum to begin comparisons
  2) **Gaussian fit method:** following what Sebouh did for the ZDC (see here)
     1) Get B in equation [2] by minimizing σ/μ ratio of $E'_{calib} = E_{em} + BE_h$
     2) Then set A in equation [2] to 1/mean of E'_{calib}/E_{par} distribution

- 3 methods (cont.)
  3) **Chi2 Method:** following what Songkyo (former ISU postdoc) did for sPHENIX (see ch. 8 of TDR)
     - Simultaneously determine A, B in equation [2] by minimizing $\sum_{events}\left(E_{calib} - E_{par}\right)^2/E_{par}^2$
- Started work on class to do this in [EpicBHCalPTDRStudies#5]
  - **Initial snag:** not familiar w/ TMinuit2 library & ROOT's unbinned fit functionality
  - So started out working on method (2) with a grid search
    - ☞ Parameter space is relatively small…
  - Then ran out-of-time and had to put out other fires :/

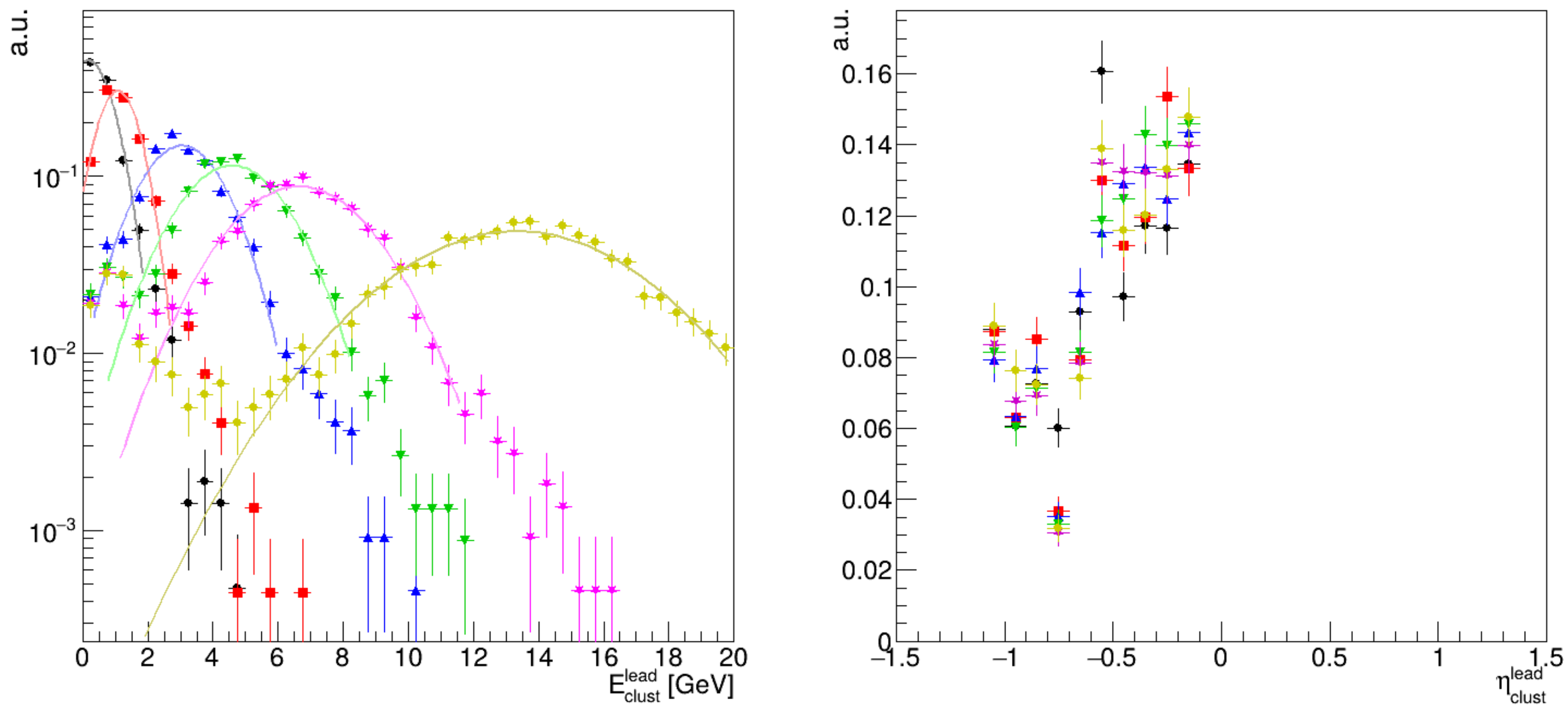
Note: Brian Page has done similar work for the NHCal, and Peter Steinberg was interested in doing something similar for the LFHCAL

BHCal Hole | The Mystery Deepens… (1/2)



Above: energy resolution (left) and linearity (right) with eta < -0.1 (so no hole). Regression is still there…

BHCal Hole | The Mystery Deepens… (2/2)



Above: lead cluster energy (left) and eta (right) with eta < -0.1 (so no hole)…

Software Planning Slides

Presented to the DSC on

02.21.2025

BHCal Specific Tasks | To-do and in-progress

Integrating calibrations in EICrecon

1) Update training to use *associations* rather than single particle events
   - ☞ Tracking info can/should also be integrated
2) Re-optimize (if needed) on realistic event topologies
3) Port models to ORT-compatible framework
   - ☞ Not strictly necessary, but desirable
4) Develop EICrecon tooling to deploy model in a reco algorithm
5) Compare against baseline (manual) regressions

Longer term to-do

- Supporting test-beam studies
  - › Importing test-beam geometry
  - › Developing data-2-JANA2 infrastructure

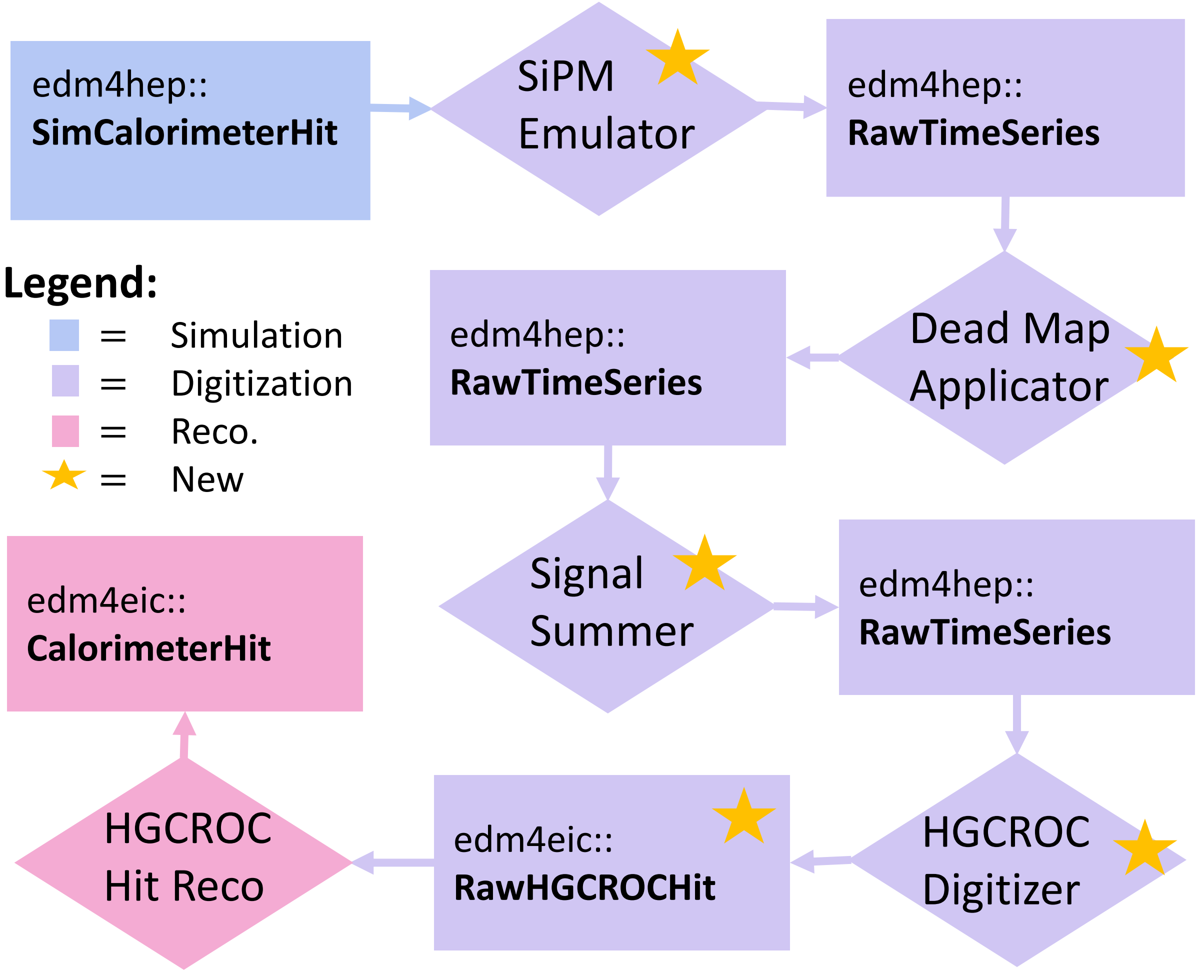
In progress tasks/studies

1) Fix misplaced tiles [epic#829]
2) Finish manual calibrations & compare against ML [EpicBHCalPTDRStudies#5]
3) Muon study from Jihee Kim (BNL)

Studies to-do

- Re-run calibrations after fixing tiles
- Check role of cluster splitting in calibration
  - › Use split/merge clusters, use sum of clusters
- Event reconstruction: EtMiss, JB variables (fig.s 8.195, 8.194)
- Jet reconstruction:
  - › Jet charged/neutral fractions vs. eta (fig. 8.177)
  - › JES/R for full jets (fig.s 8.196, 8.178)

HGC/CALOROC Digitization | Overview



- **Longstanding goal of LFHCAL group:**
  - Under discussion for a while…
    - [02.28.2024] LFHCAL mtg.
    - 2024 EIC UGM
  - Haven't had the FTEs to implement, though!
- **BIC DSC also studying CALOROC digitization in simulation**
  - See Maria's slides from previous Calo CCWG
- **Now hoping to kick off joint effort b/n LFHCAL, BIC, and BHCal (and more?) to actually implement!**

HGC/CALOROC Digitization | Preliminary Task List

Item	PR/Issue	Assignee/Interested	Target	Notes
Add SiPM++ to shell	n/a	Wouter D. (UM)	Done	See here in eic/spack
SiPM waveform generation algo	To-Do	Afnan S. (LLR), Deepa T. (UT)	TBD	i.e. run SiPM++
HGCROC raw hit type	EDM4eic#101	Derek A. (ISU)	April	Under discussion
Waveform summation algo	To-Do	Fredi B. (ORNL)	TBD	
HGCROC digitization algo	To-Do	Derek A. (ISU)	TBD	
HGCROC reconstruction algo	To-Do	Matt Ng. (LLR)	TBD	

- **Above:** preliminary list of tasks as sketched out during 2024 Lehigh discussion
  - **Likely will evolve significantly after discussion with BIC team!**
- **Note:** SiPM++ (a.k.a. SimSiPM) will need a little vetting
  - Alternatively, can build on approaches other subsystems have taken
    - ☞ e.g. TOF and dRICH

Particle Flow | EICrecon Development

Item	PR/Issue	Assignee	Target	Notes
Track-Cluster Matcher	EICrecon#1694	Tristan P. (Lehigh)	Late-Feb.	
PFA0: Update Merge/Splitter	EICrecon#1699	Derek A. (ISU)	Mid-Feb.	Review in-progress!
PFA1(a): Track-Cluster Subtractor	EICrecon#1627	Derek A. (ISU)	Late-Feb.	In dev branch
Charged/Neutral Particles Candidates	EDM4eic#97	Derek A. (ISU)	March	In dev branch
PFA1(b): Charged Candidate Regressor	To-Do	Derek A. (ISU)	March	
PFA2: Remnant Combiner	To-Do	Derek A. (ISU)	April	Might overlap w/ topocluster
PFA3: Particle Converter	To-Do	Derek A. (ISU)	April	
Cross-Calo Topocluster Maker	EICrecon#1561	Tristan P. (Lehigh)	April	

- **Reco WG Priority:** implement PF baseline by 1st half of this year
  - *Significant synergy* with BHCal DSC (and others)!
  - See PF Summary at January CM
- PFA and related machinery critical for BHCal physics:
  a) Full jet reconstruction,
  b) Calo-based lepton ID (i.e. muons),
  c) Neutral reconstruction (i.e. neutrons),
  d) Hadronic final state

Particle Flow | Associated tasks

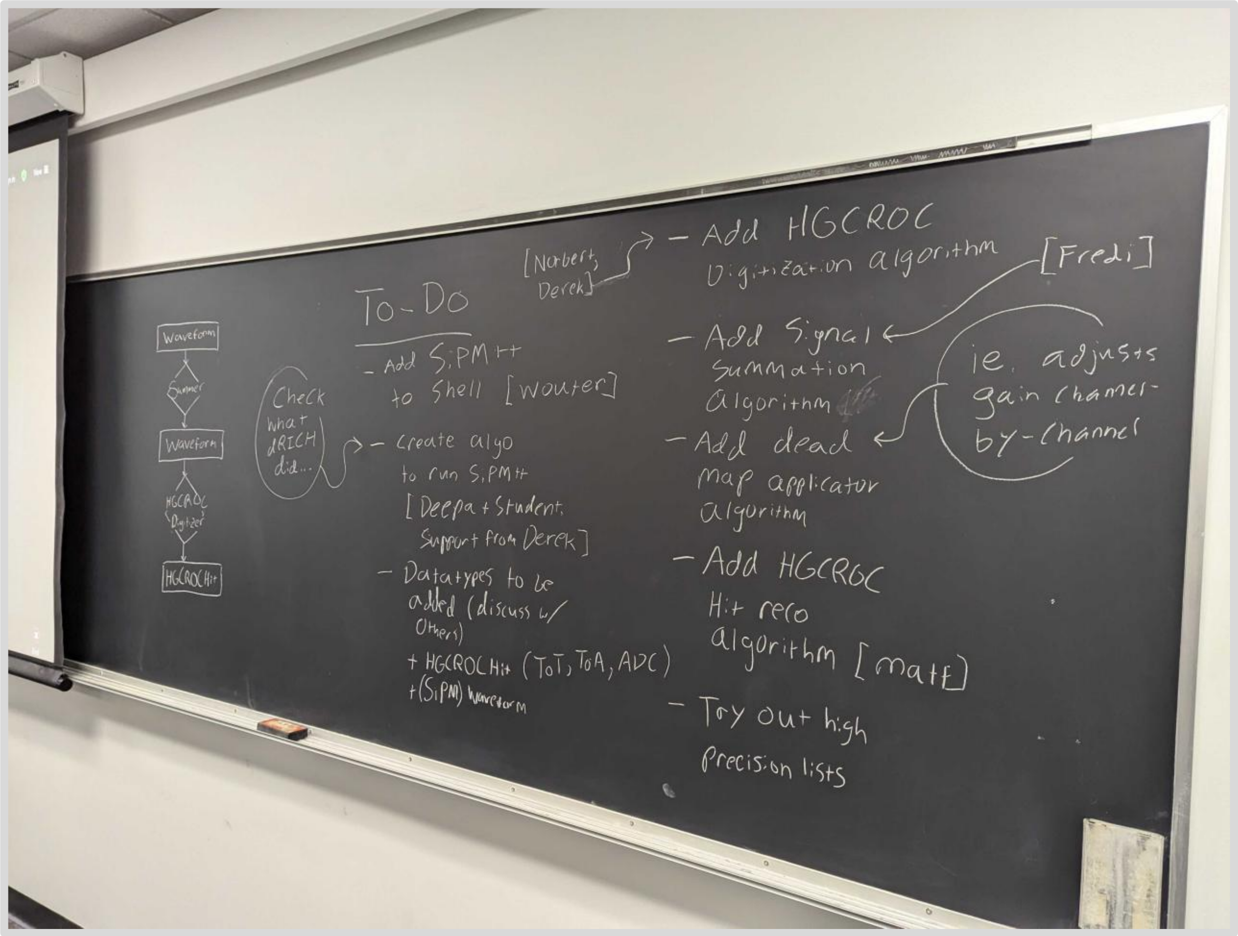
Component	Parameter Tuning	Benchmarking
Track-Cluster Matcher	In progress	To-Do
PFA0: Merge/Splitter	Some done*	To-Do*
PFA1(a): Subtractor	To-Do	To-Do
PFA1(b): Charged Regressor	To-Do	To-Do
PFA2: Remnant Combiner	To-Do	To-Do
PFA3: Neutral Regressor	To-Do	To-Do
CC Topocluster Maker	In progress	To-Do

- **Beyond development:** significant amount of work to be done tuning parameters/benchmarking implementations!
- **New workforce!** Several additional people expressed interest in helping out
  - Olaiya Olokunboyo (NHU)
  - Subhadip Pal (CTU)
  - David Ruth (NHU)
  - Peter Steinberg (BNL)
  - **Thanks!!** 🙏

* **Notes:**
  - Some parameter tuning done for initial implementation
    - ☞ BIC still needs tuning, NHCal should be revisited
  - Benchmarking can build off existing plugin used for testing

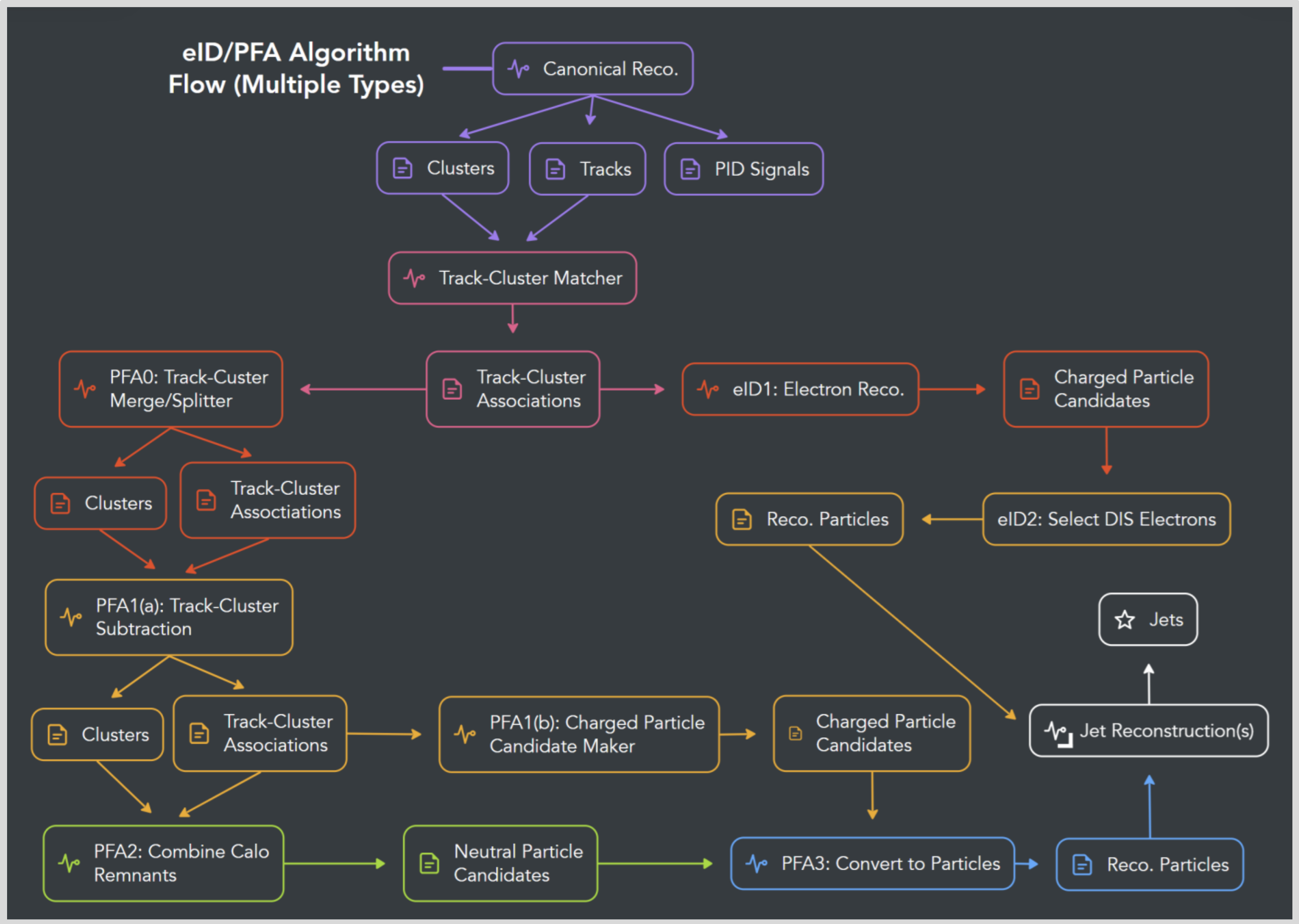
Backup | The Infamous Blackboard

- **Right:** picture of notes from LFHCAL/NHCal discussion at the 2024 Lehigh UGM
  - Sketches out individual tasks/path towards implementation
  - But we need to find the time to actually do it :/
- **Note:** other tasks specified in list
  - Check impact of high-precision physics lists on LFHCAL response
  - Implement BHCal, LHFCAL test beam geometries in DD4hep



Backup | PFA Algorithm Flow

- **Right:** schematic of the proposed sequence of PF algorithms/types
  - Also illustrates how output will interface with jet reconstruction



BHCal-Only Resolution

Post-GDML (With Hole)

Presented to the DSC on

11.01.2024

Digi/Reco Parameters | Summary

- **Digitization parameters [HGCROC]**
  - ADC cap = 65536 (16 bit ADC)
  - ADC dynamic range = 1 GeV
  - ADC mean pedestal = 300
  - ADC pedestal sigma = 2
  - TDC resolution = 1 ps
  - Time cap = 100 ns (4 HGCROC samples)
- **Tile ("hit") energy reconstruction**
  - ADC threshold = 33 (pedSigmaADC + threshold = half of a MIP = 333 ADC)
  - Sampling fraction = 0.033 (from sPHENIX simulations
- **Clustering parameters**
  - Minimum energy = 5 MeV
  - Minimum seed energy = 30 MeV
  - Log weight base = 6.2
  - Adjacency matrix = (see right)

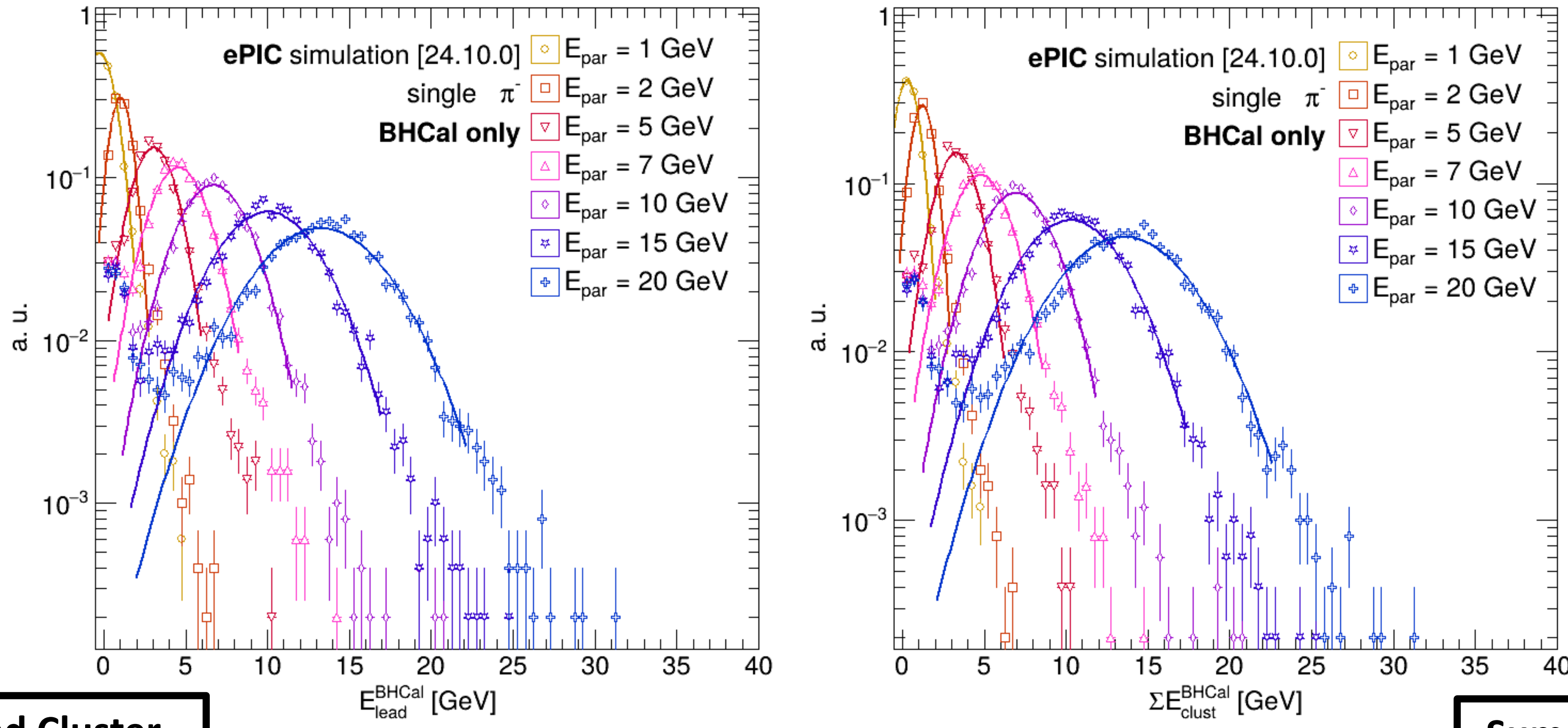
- **Merging parameters (based on single pion studies)**
  - Average E/p = 50%
  - E/p sigma = 0.25
  - Delta-R merge = 0.40 sr

☞ **Reminder:** can always check all parameters here

Adjacency Matrix

```
"("
  // check for vertically adjacent tiles
  "  ( (abs(eta_1 - eta_2) == 1) && (abs(phi_1 - phi_2) == 0) ) ||"
  // check for horizontally adjacent tiles
  "  ( (abs(eta_1 - eta_2) == 0) && (abs(phi_1 - phi_2) == 1) ) ||"
  // check for horizontally adjacent tiles at wraparound
  "  ( (abs(eta_1 - eta_2) == 0) && (abs(phi_1 - phi_2) == (320 - 1)) )"
") == 1"
```

BHCal-Only Check | Energy Spectra

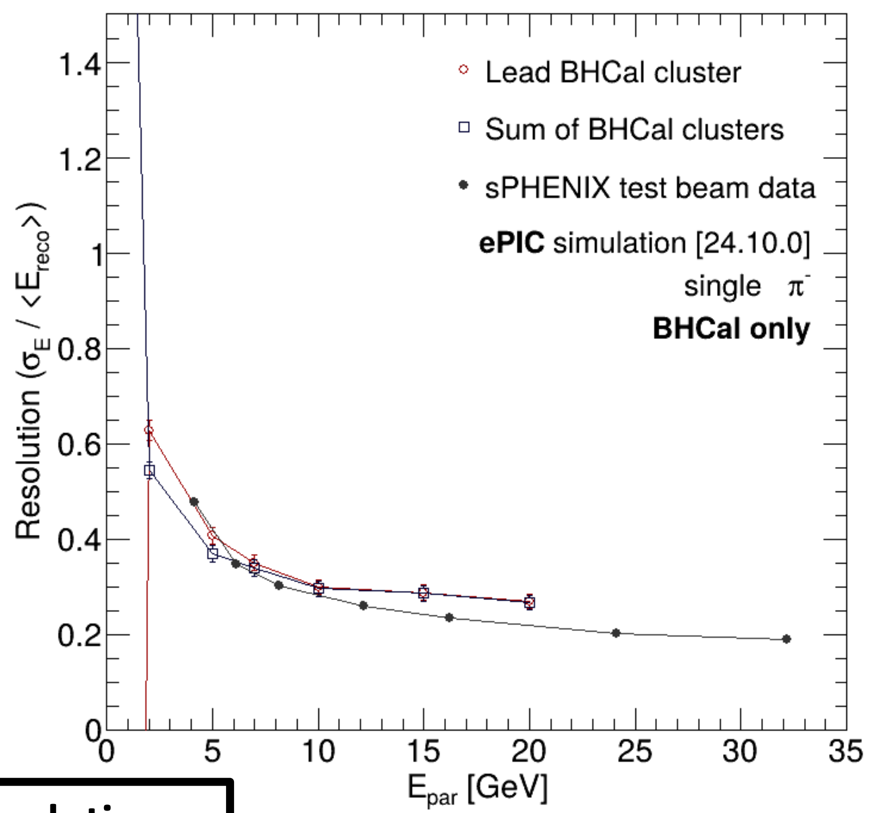


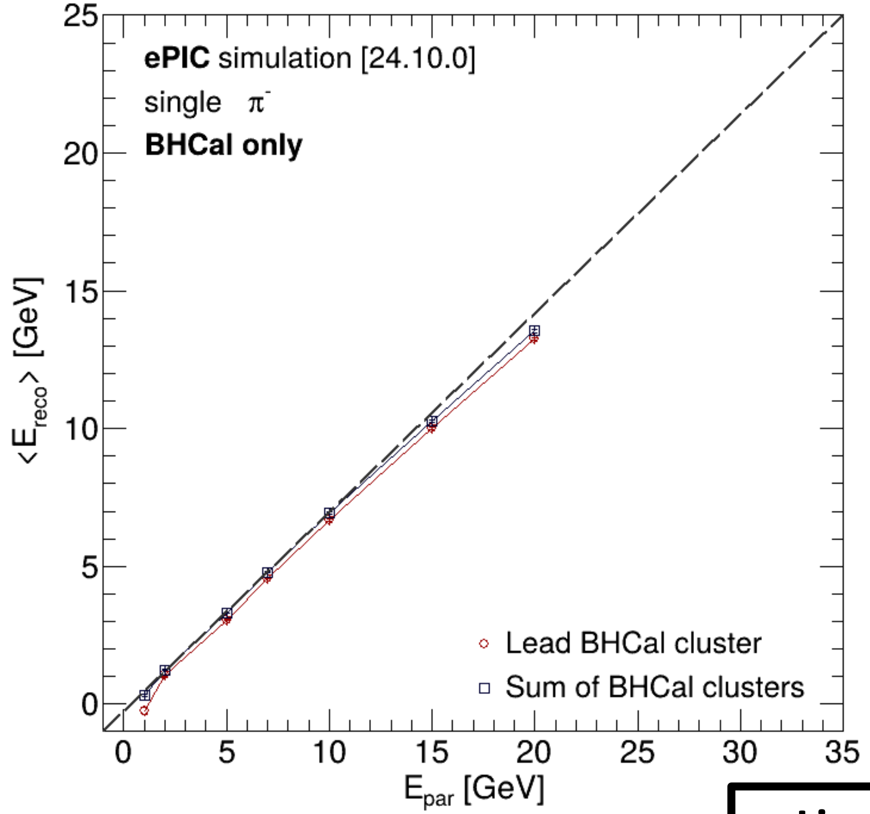
Lead Cluster

Sum of Clusters

- Simulated single π^- **w/ E = 1 - 20 GeV** in just the BHCal
  - Using 24.10.0 geometry, generated vertex = (0, 0, 0)

BHCal-Only Check | Resolution vs. Linearity



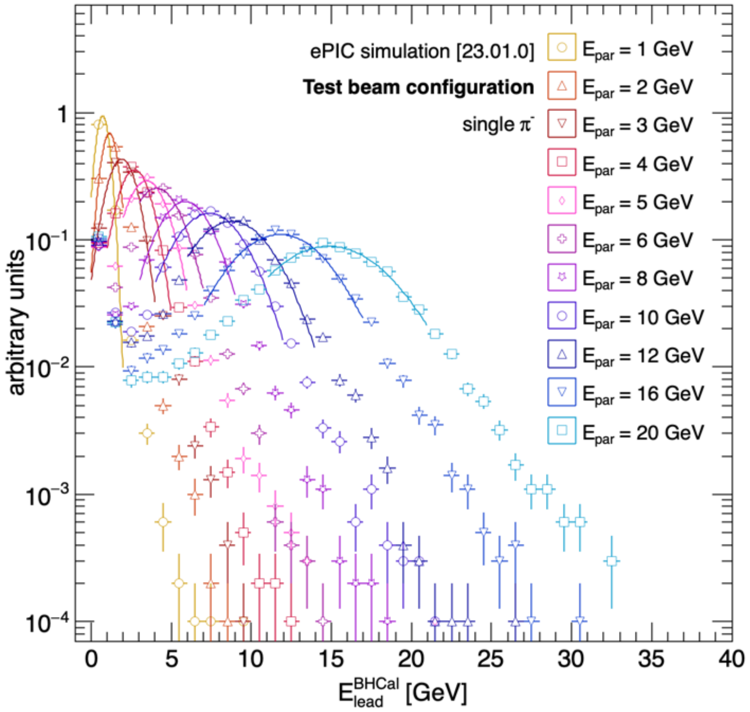


Resolution

Linearity

- Simulated single π^- **w/ E = 1 - 20 GeV** in just the BHCal
  - Using 24.10.0 geometry, generated vertex = (0, 0, 0)
  - **Red = lead clusters**, **Blue = sum of clusters**

BHCal-Only Check | Tower vs. Tile Energies



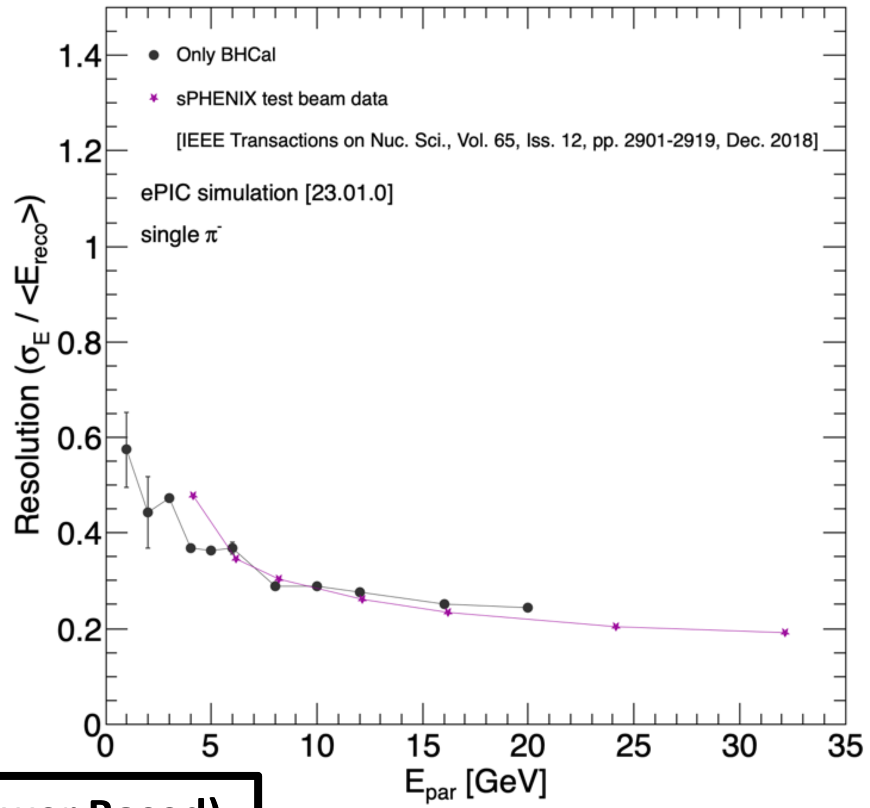
- Simulated single π^- w/ E = 1 - 20 GeV in just the BHCal
  - New using 24.10.0 geometry, tile readout
  - Old using 23.01.0 geometry, tower readout
  - Both using generated vertex = (0, 0, 0)

Old (Tower Based)

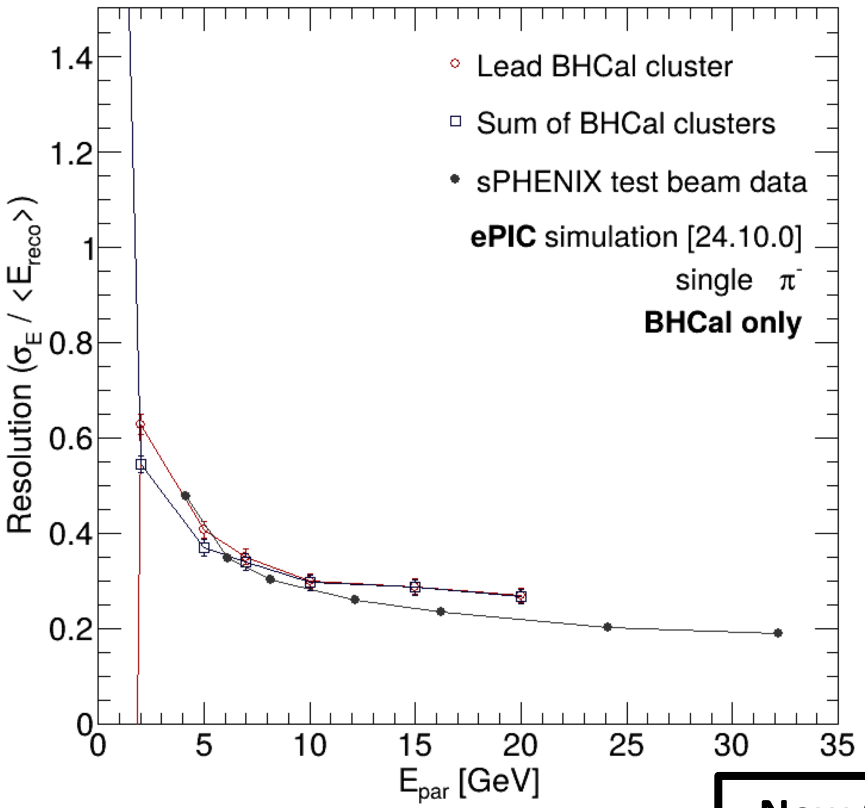
- Simulated single π^- w/ E = 1 - 20 GeV in just the BHCal
  - New using 24.10.0 geometry, tile readout
  - Old using 23.01.0 geometry, tower readout
  - Both using generated vertex = (0, 0, 0)

New (Tile Based)

BHCal-Only Check | Tower vs. Tile Resolution



Old (Tower Based)



New (Tile Based)

- Simulated single π^- **w/ E = 1 - 20 GeV** in just the BHCal
  - Using 24.10.0 geometry, generated vertex = (0, 0, 0)
  - **Red/black = lead clusters, Blue = sum of clusters**

Hole Mystery Slides

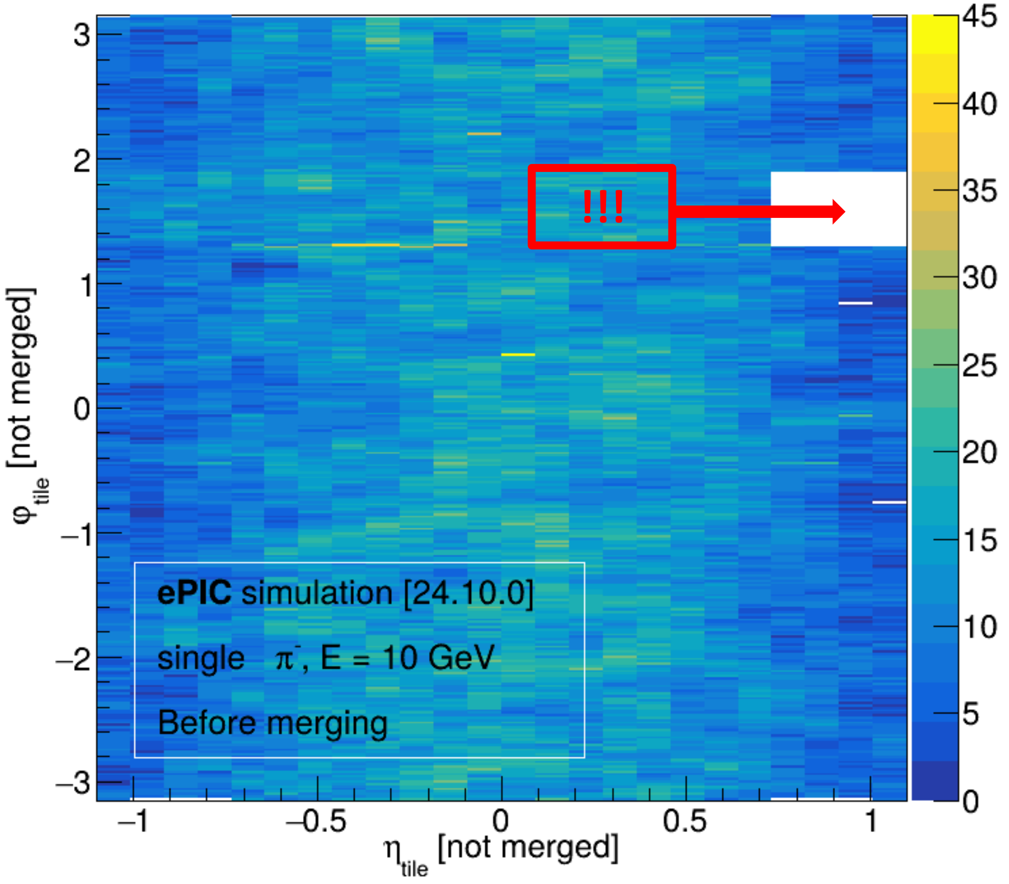
Presented to DSC on

02.14.2025

The Hole Mystery | context

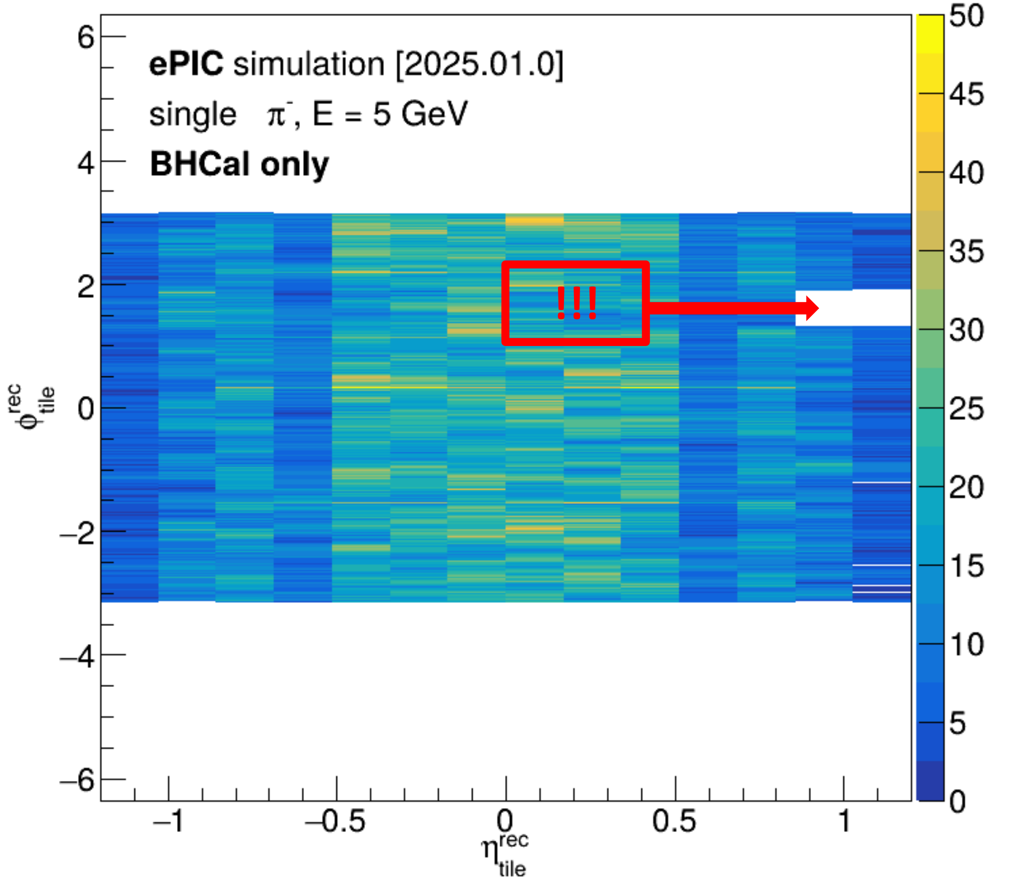
- **Late last year:** noticed a mysterious hole had appeared in our acceptance
  - *Definitely* was not there in 2023…
  - And wasn't clear if it corresponding to a specific feature
    - ☞ e.g. *definitely* not the chimney sector

- **Right:** eta/phi of tiles from 2024.10.0 geometry
  - Single 10 GeV pi- events



The Hole Mystery | check 0: can I reproduce it?

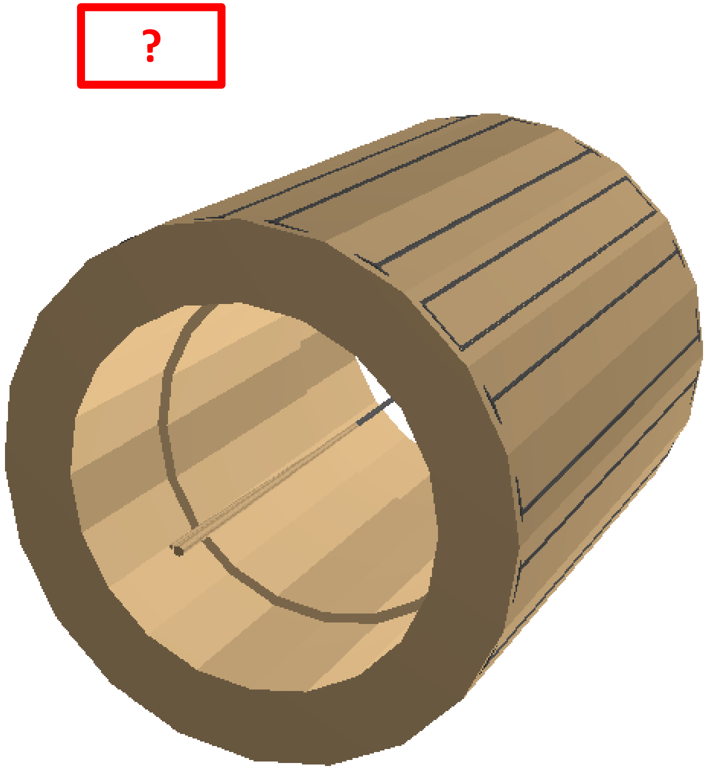
- As a 0th order check, wanted to confirm that it was still pesent in the latest geometry
  - It is
- **Right:** eta/phi of tiles from **2025.01.0** geometry
  - "BHCal-only" configuration
    - i.e. BHCal + beampipe
    - **epic_bhcal.xml**
  - Single 5 GeV pi- events
  - **Note:** tiles are *reconstructed*, so after digitization + thresholds have been applied
    - ☞ Hole is *also* seen for sim hits



The Hole Mystery | check 1: how does the geom look?

- Quick check: exported 2025.01.0 geometry to see if anything was *immediately* apparent
  - **Not really**

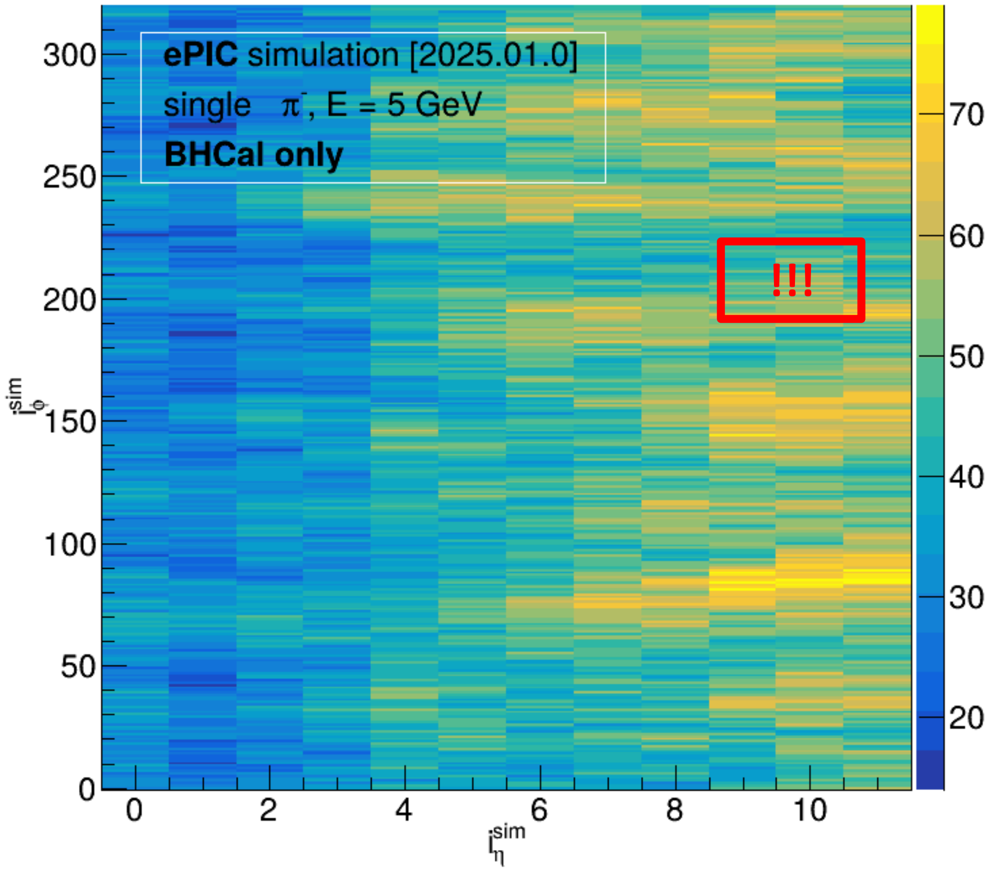
- **Right:** exported BHCal-only 2025.01.0 geometry



The Hole Mystery | check 2: do we hit all indices?

- Next, wanted to check to see hit every possible eta/phi index of the tiles
  - **We do!**
  - ☞ If some aren't being placed (or etc.), then we should also see a hole in *this* distribution

- **Right:** eta/phi *index* of tiles from **2025.01.0** geometry
  - Same configuration, single 5 GeV pi- events
  - **Note:** tiles are *simulated*, so these correspond to the sum of G4hits

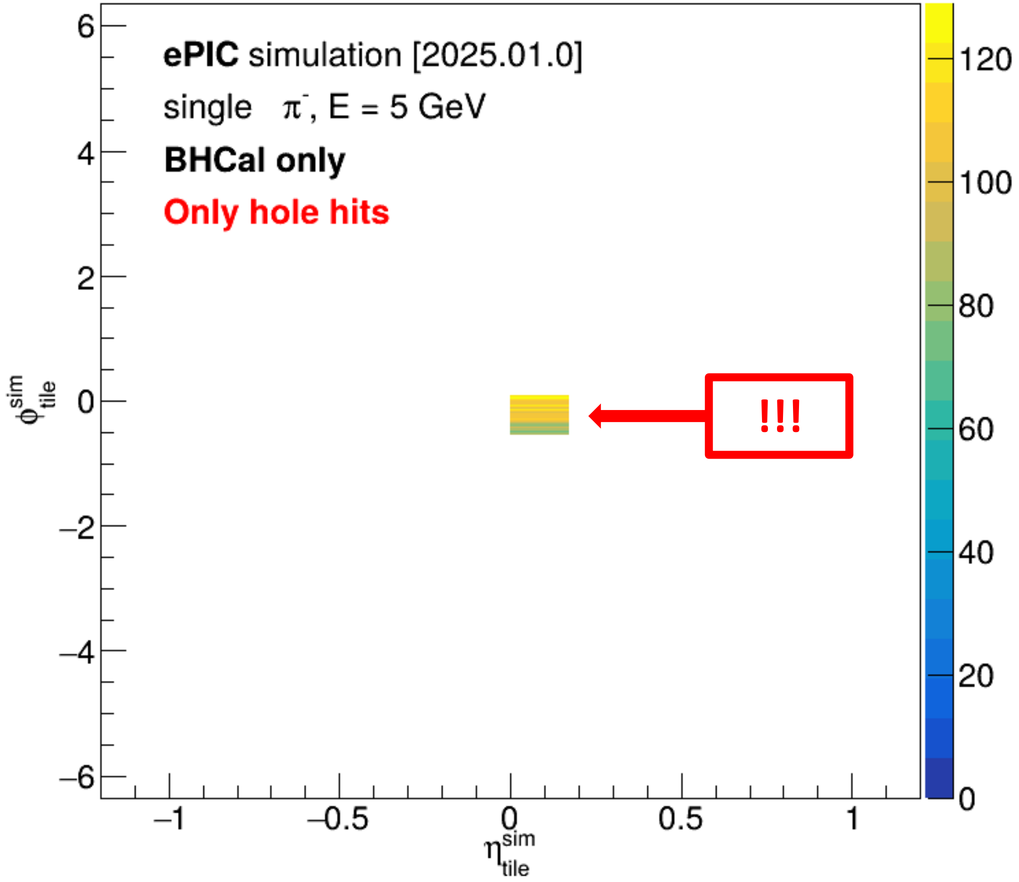


The Hole Mystery | check 3: eta/phi of hole tiles?

- Lastly, we know what the indices of the hole should be roughly ieta = 10 - 11, iphi = 226 ~ 256
  - ☞ **And we know that all indices are being hit, so what are the hole tiles' eta/phi?**

- **Right:** eta/phi of sim tiles w/ eta/phi indices in above range from **2025.01.0** geometry
  - **Looks like they just haven't been translated from the origin!**
  - – Same configuration, single 5 GeV pi- events

- **Next steps:** should be fairly easy fix, so will open an issue on GitHub and go from there



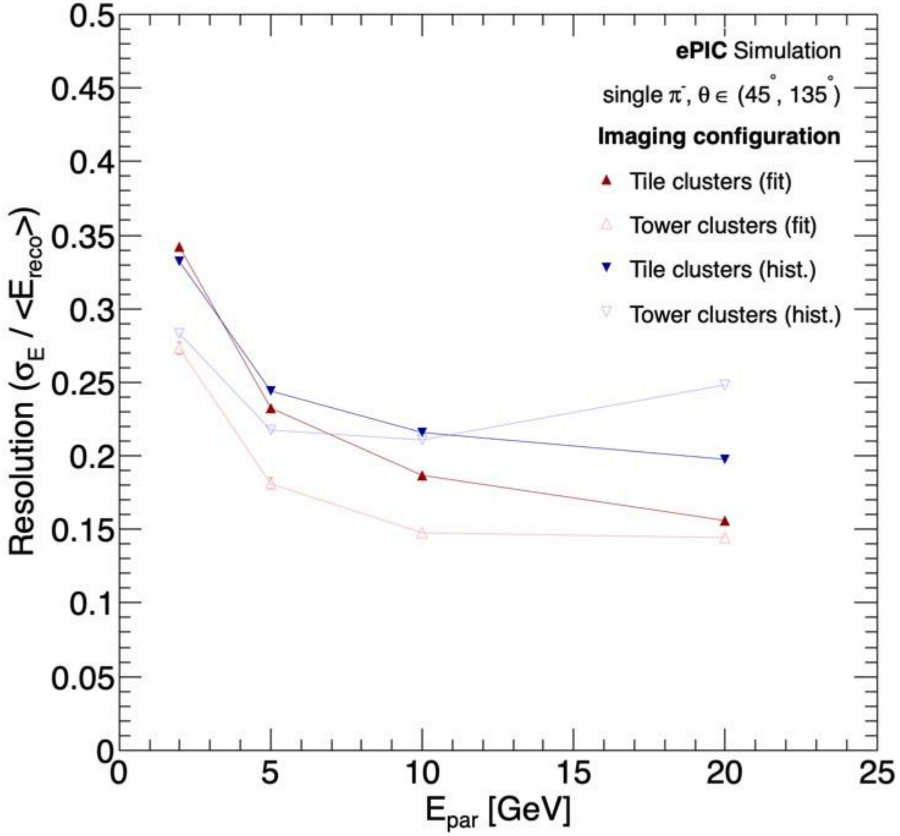
Tile vs. Tower Threshold Comparisons

Pre-GDML Transition

Presented to ISU Group on

07.14.2023

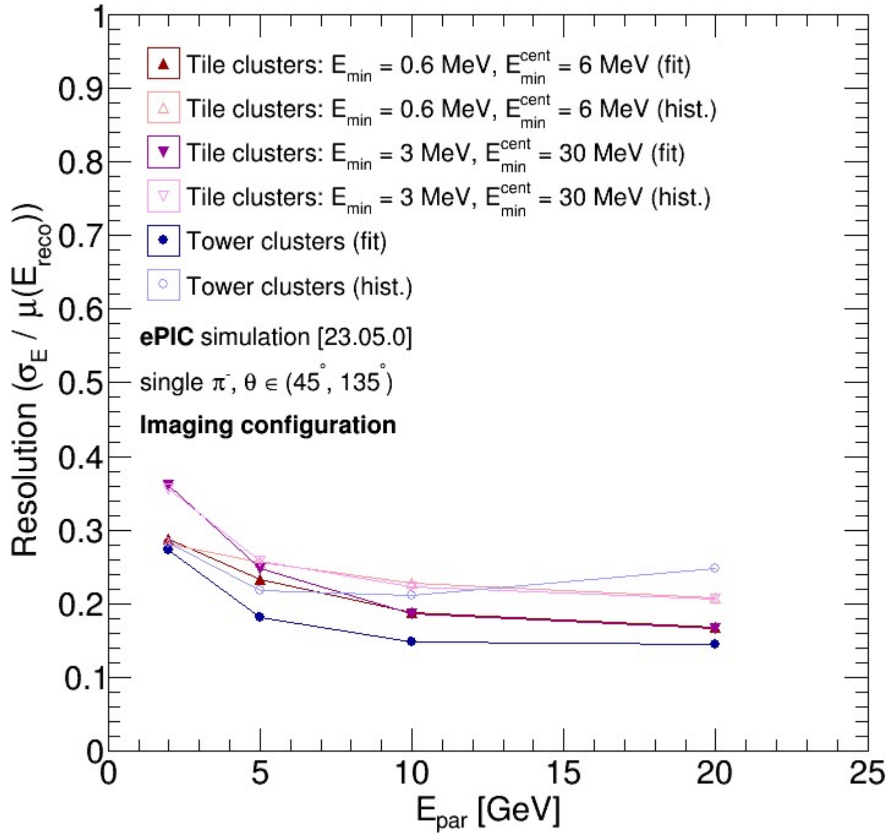
Tile vs. Tower Clusters | 1st resolution comparison



- Initial comparison of resolution from tower-based vs. tile-based clusters
  - Tile clusters **(closed markers)** made with **epic [23.05.0]**
  - Tower clusters **(open markers)** made with **epic [23.01.0]**
    - These were from study presented in March

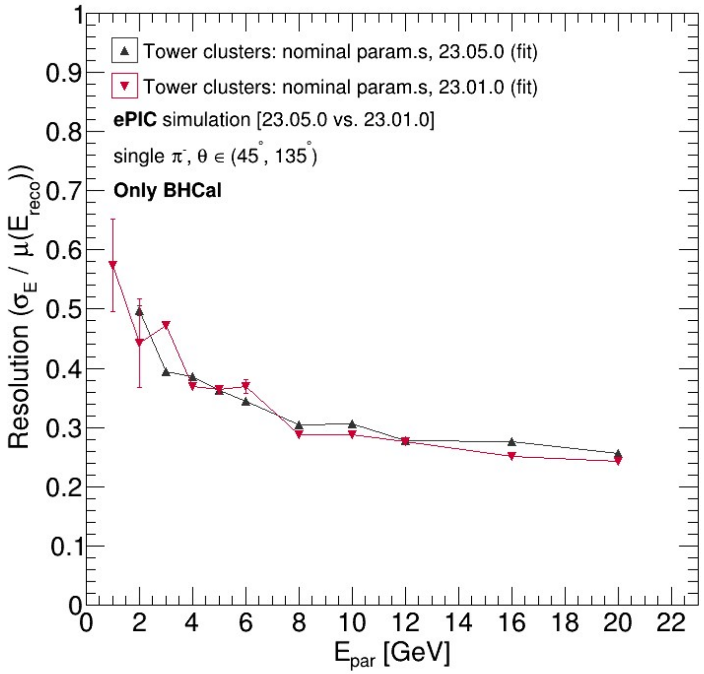
- Discrepancy suspected to be due to energy thresholds not being tuned for tiles
  - $E_{min} = 3$ MeV (min. energy to be added to cluster)
  - $E_{min}^{cent} = 30$ MeV (min. energy of cluster's central tower)

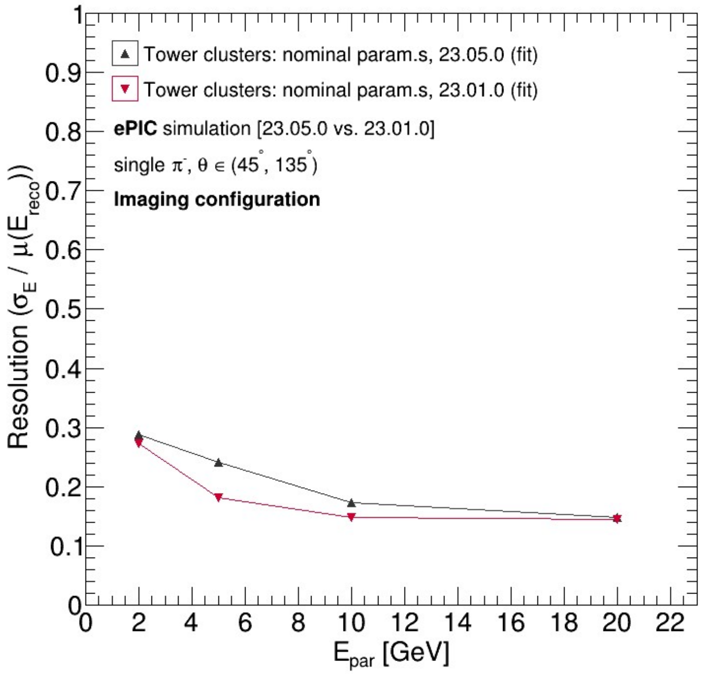
Tile vs. Tower Clusters | varying energy parameters



- Reduced energy thresholds by 1/5th (since 5 tiles per tower)
  - $E_{min} = 0.6$ MeV
  - $E^{cent}_{min} = 6$ MeV
- **Lowering energy thresholds improves resolution!**
  - Compare **red markers** (default thresholds) against **magenta** (reduced thresholds)
  - Towers clusters **(blue markers)** still do better though…
- Since tower clusters came from version [23.01.0], I wanted to compare tower clusters from [23.05.0]
  - Make sure I get (roughly) the same resolution as in March…

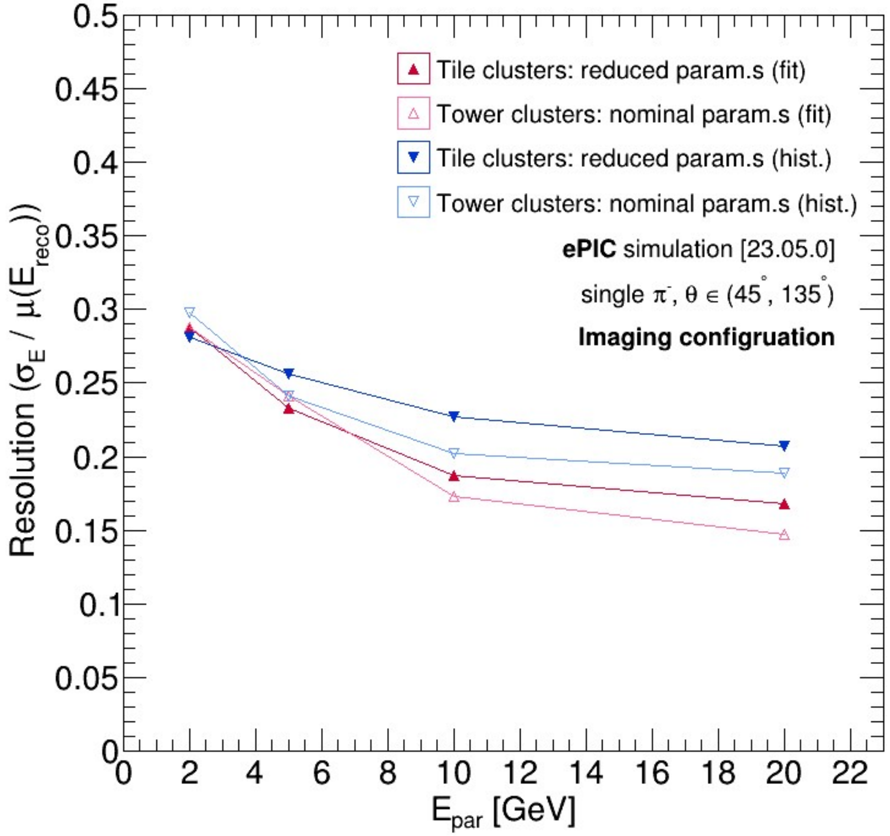
Tile vs. Tower Clusters | old vs. recent tower clusters





- [23.05.0] **(black markers)** vs. [23.01.0] **(red markers)** tower clusters for
  - **Left:** only BHCal
  - **Black:** full detector (Imaging)
  - Energy thresholds same and at default
- **Resolutions agree for BHCal-only** (as we would hope)
  - But [23.05.0] resolution is a little worse for full detector…

Tile vs. Tower Clusters | 2^{nd} resolution comparison



- To close the loop: left is comparison of resolutions from tile clusters **(closed markers)** vs. tower clusters **(open markers)**
  - All made with **epic [23.05.0]**
  - Tiles use reduced energy thresholds, and towers use default energy thresholds

- **Much closer now!**

Tile vs. Tower Comparisons

Pre-GDML Transition

(Includes BHCal-Only Resolution)

Poster for the

2023 RHIC/AGS Annual Users Meeting

Derek Anderson
Iowa State University
for the ePIC Collaboration

PERFORMANCE AND CALIBRATION OF THE EPIC BHCAL

Abstract

Measurement of jets and their substructure will provide valuable information about the properties of the struck quarks and their radiative properties in Deep-Inelastic Scattering events. The ePIC Barrel Hadronic Calorimeter (BHCal) will be a critical tool for such measurements. By enabling the measurement of the neutral hadronic component of jets, the BHCal will complement the Barrel Electromagnetic Calorimeter and improve our knowledge of the jet energy scale. However, to obtain a physically meaningful measurement, the response of the BHCal must be properly calibrated. We provide a snapshot of ongoing studies exploring the use of Machine Learning to calibrate the response of the BHCal.

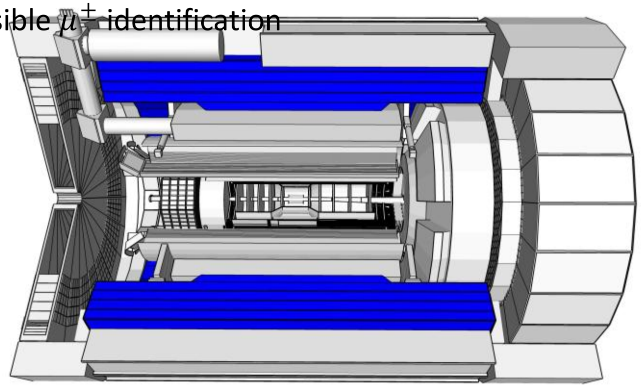
Derek Anderson
Iowa State University
for the ePIC Collaboration

PERFORMANCE AND CALIBRATION OF THE EPIC BHCAL

(1) Introduction

- **The BHCal will serve several roles at ePIC:**
  - Precise jet energy reconstruction (by incl. h^0)
  - Add. Handle on e^- kinematics
  - Solenoid flux return
  - Possible $\mu^\pm$ identification

- ePIC planning to reuse (outer) sPHENIX HCal
- **Below:** rendering of current design of the central ePIC detector
  - ☞ BHCal highlighted in blue



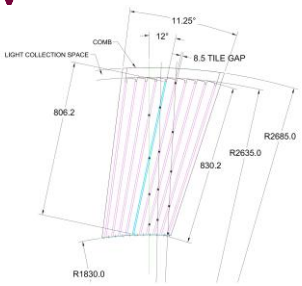
Derek Anderson
Iowa State University
for the ePIC Collaboration

PERFORMANCE AND CALIBRATION OF THE EPIC BHCAL

(2) BHCal Geometry

- Shashlik Geometry:
  - Alternating steel & scintillating tile (+ WLS fibers)
  - $|\eta| < 1.1$, 2π coverage
    - 48 towers/sector, 32 sectors
    - 5 tiles/tower
  - $\Delta\eta \times \Delta\varphi \sim 0.1 \times 0.1$
- sPHENIX reads out each tower with SiPMs

☞ **ePIC will read out each tile**

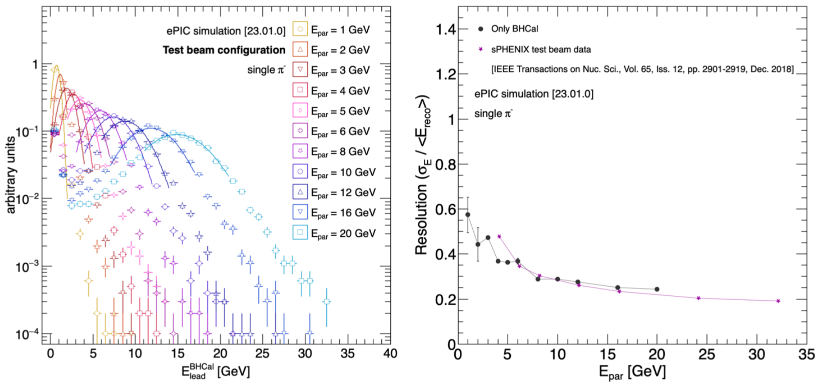


Derek Anderson
Iowa State University
for the ePIC Collaboration

PERFORMANCE AND CALIBRATION OF THE EPIC BHCAL

(3) Simulation Implementation

- BHCal implemented in DD4hep simulation of ePIC
  - **Left:** reconstructed energies in ePIC BHCal for single π^-
  - **Right:** resolutions from ePIC simulation vs. sPHENIX test beam data
    - **IEEE Transactions on Nuc. Sci., Vol. 65, Iss. 12, pp. 2901 – 2919, Dec. 2018**



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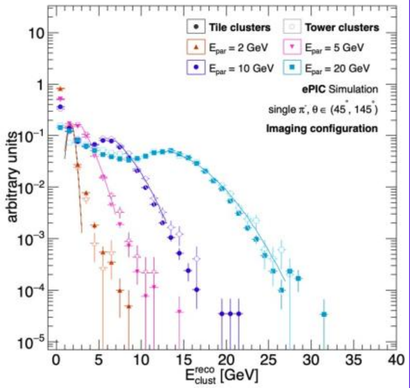
(4) Calibration Motivation

- Energy measured by BHCal degraded for several reasons:
  - Inefficiencies in clustering
  - Fluctuations in hadronic and EM parts of shower
  - Energy loss in inactive material
  - Loss due to nuclear-binding energies
  - Etc.
- **Right:** reconstructed energy of highest energy cluster in BHCal
  - ☞ **Measured energy has to be calibrated!**



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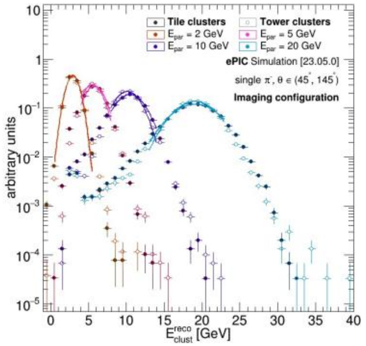
(5) Calibration Strategy

- EM part of shower corrected for
  - Nuclear binding energy etc. still need to be corrected
- ☞ **Used TMVA:**
  - Trained on single particle events
  - Regression analysis:
    - Particle energy as target
    - Using info of highest energy clusters from BECal/BHCal
- Calibrated energies **(right)** still show significant tails
  - Due to (unwanted) cluster splitting?



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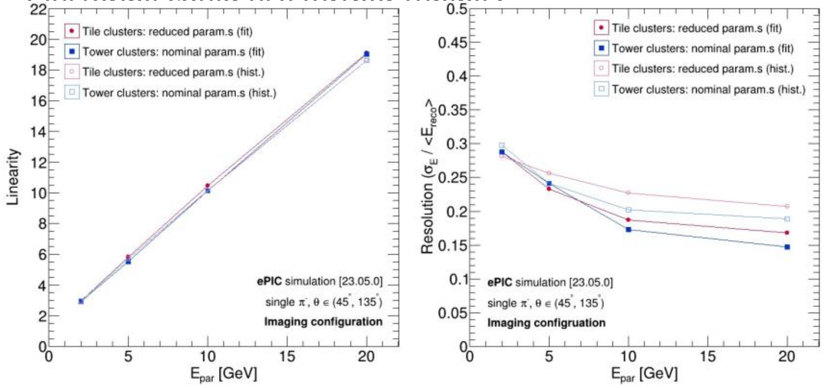
(6) Energy Resolution

- **Below:** linearity **(left)** and resolution **(right)** for tile- vs. tower-based clusters
  - Tower-based cluster resolution slightly better than tile-based
  - Clustering could use further tuning?



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PERFORMANCE AND CALIBRATION OF THE EPIC BHCAL

(7) Future Work

- **Near-term goals with calibration:**
  - Make use of full capability of imaging BECal
    - ☞ Segmentation gives additional information on shower
  - Improve ML model for calibration
    - › Hyperparameter scan
    - › Extend model to split clusters?
  - Integration into EIC software

- **Planned studies in near-term:**
  - Evaluate response to h^0 (e.g. neutrons)
  - Study response to $\mu^{\pm}$
  - Study impact on JES in realistic DIS events

Barrel HCAL Electronics Chain and Requirements

Presented to the Calo CCWG on 08.09.2023 by

J. Lajoie

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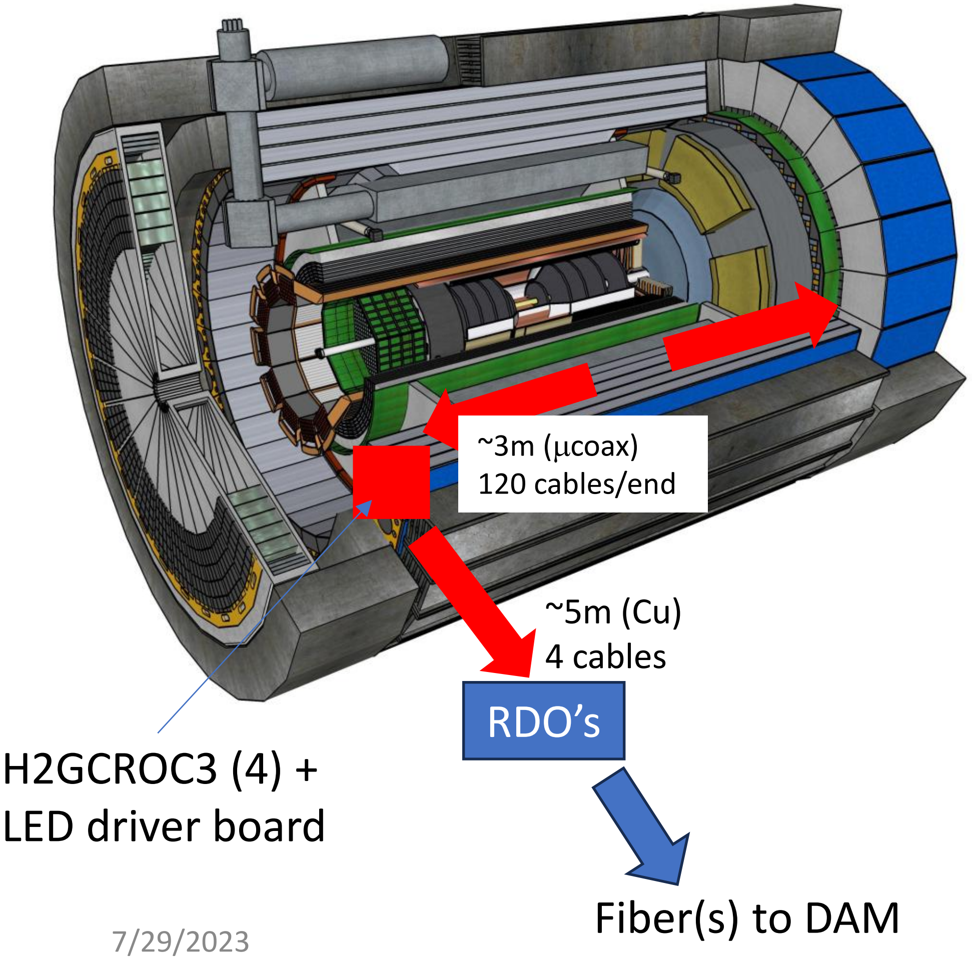
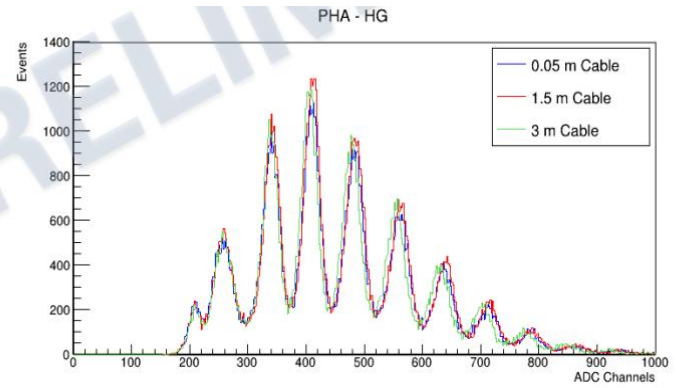
Iowa State University

Readout Chain

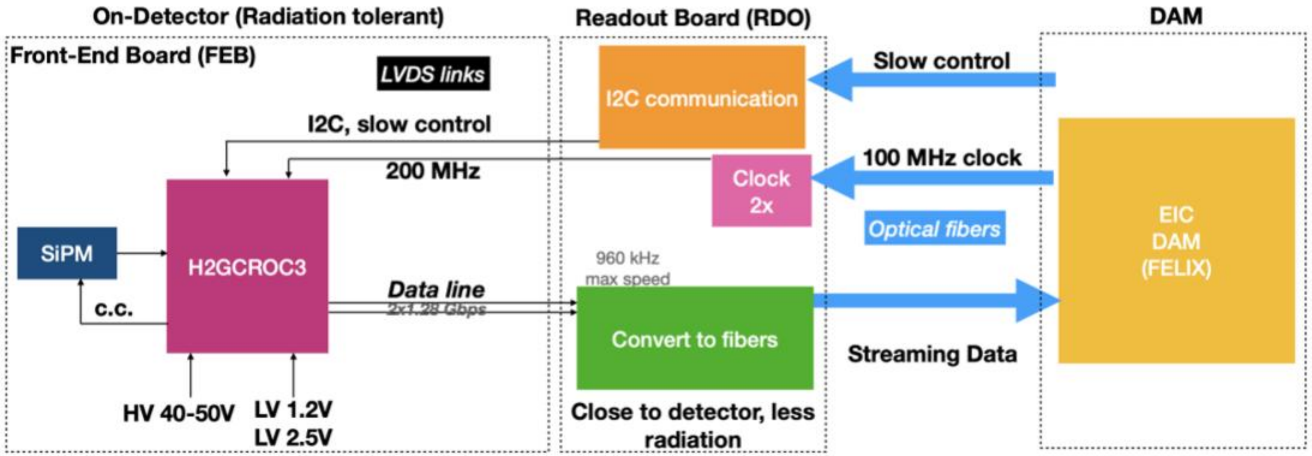




Energy loss along a cable with remote SiPM

One sector -> 8 H2GCROC3 boards. Cable SiPM's out to end of barrel HCAL to keep accessible for maintenance.

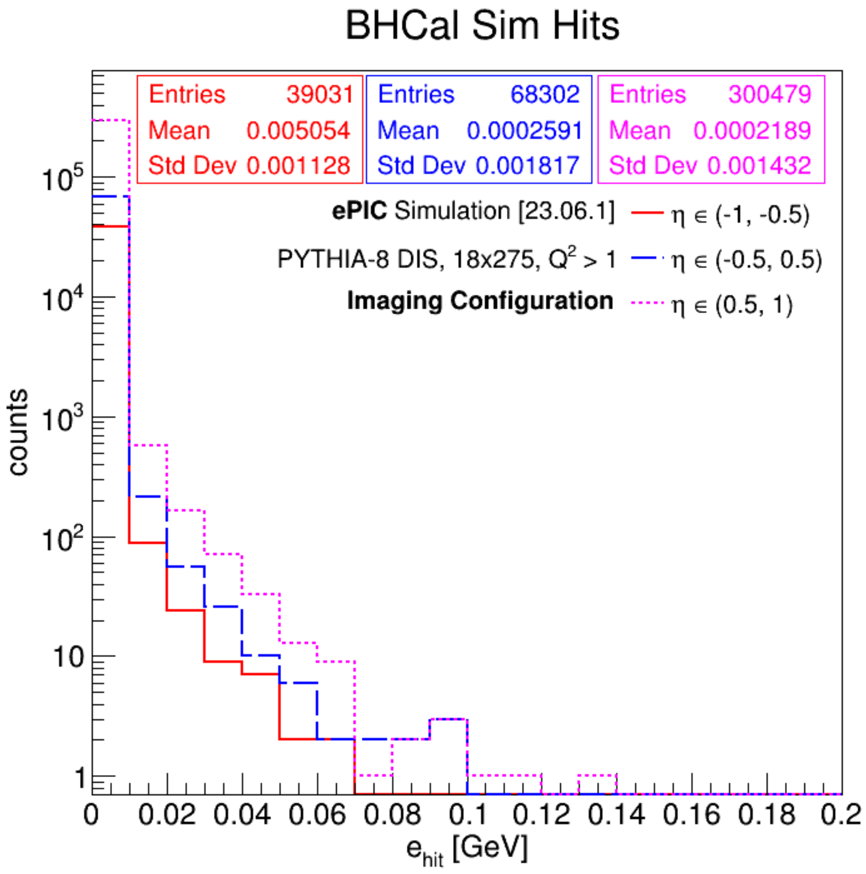
LFHCal readout hierarchy (after the upgrade)



SiPM Specifications

Barrel Hadronic Calorimeter		
Parameter	**Specification**	**Notes**
Active Area	3mm x 3mm	
Pixel Size	15 micron	
Package Type	surface mount	
Peak Sensitivity	~460 nm	
PDE	~25%	
Gain	~2 x 10^5	
DCR	1kHz typical/2kHz max	
Temperature coefficient of Vop	<60 mV/C	
Direct crosstalk probability	<1%	from S14160-3015PS, not specified for S12572-015P
Terminal capacity	~500pF	
Packing granularity	N/A	
Vop variation within a tray	+/-0.1V	sPHENIX was +/- 0.04, 0.1V is from Hamamatsu quote, should be OK
Recharge Time	N/A	probably should have a spec here, but not sure from datasheets?
Fill Factor	~50%	yields approximately 40k pixels
Protective Layer	Silicone or epoxy resin (n=~1.55)	this probably doesn't need to be a spec for oHCAL?
	NB: Specifications set to match sPHENIX - Hamamatsu S12572-015P	
	Crosschecked against datasheet for Hamamatsu S14160-3015PS	

Readout Requirements – Dynamic Range



This is the distribution of energy deposited in the scintillating tiles (*visible* energy) in an ePIC simulation of 18x275 GeV DIS events (10k events total). The regions are split in rapidity, and the higher overall energy deposition at positive rapidity is visible.

0.3 GeV of *visible* energy corresponds to ~1300 SiPM pixels firing
Single muon requirement sets lower limit at ~26 pixels
(see backup, using sPHENIX calibration and new SiPM).

ePIC plans to use the Hamamatsu S14160-3015PS SiPM, operated at ~3.6x10^5 gain (about 4V over breakdown, or ~42V). The terminal capacitance of the S14160-3015PS is 530pF at V_{op}. Therefore, the junction capacitance is

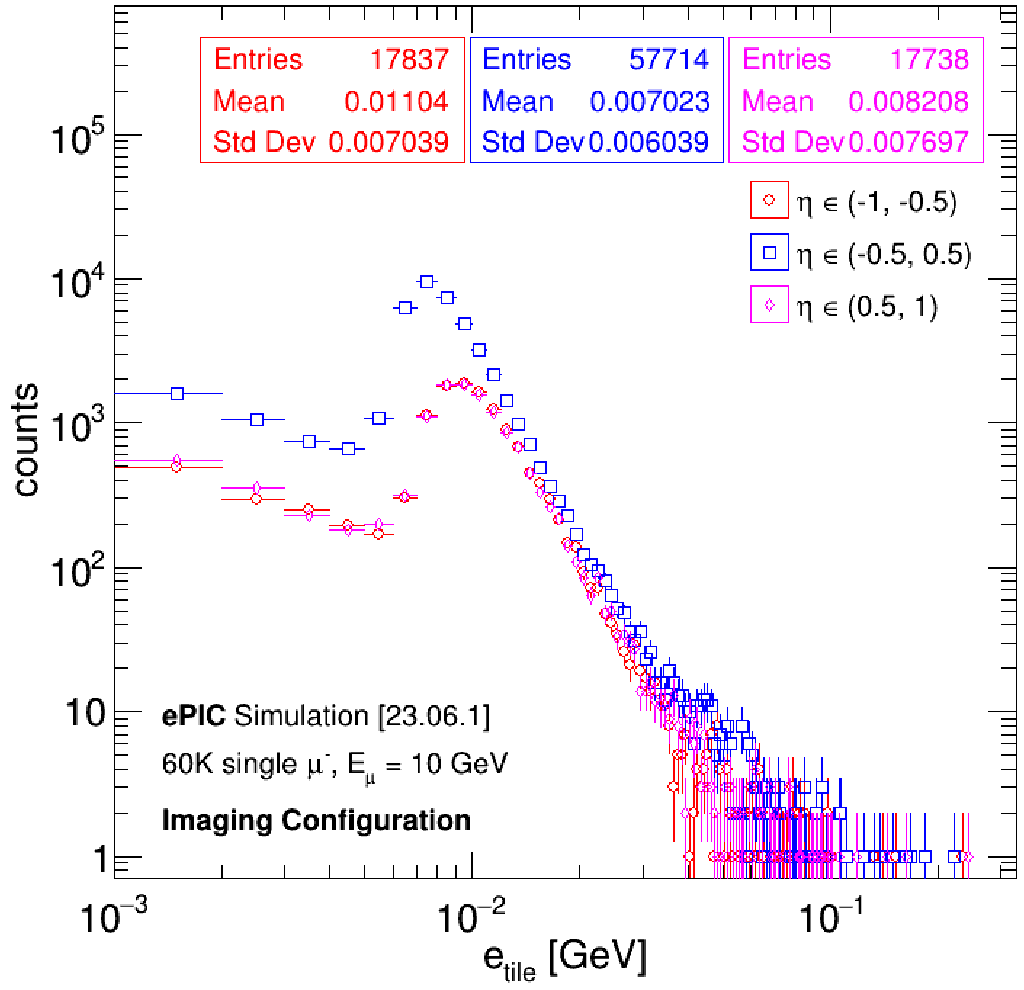
$$C_J = \frac{C_T}{N_{pix}} = \frac{530pF}{39984} = 13\text{fF}$$

This gives a single pixel charge output of $Q = C_J \Delta V$ = 13fF x 4V = 52fC

Combined with the dynamic range of fired pixels (26-1300) this means the charge range we would see is 1.3 – 68 pC. Of course, we would want more resolution in the lower range from the HGCROC ADC and then resolution at higher amplitudes from the TOT.

The H2GCROC3 expected range is 1-16pC (ADC), 16-320pC (TOT)

Muons in Simulation



Single muon peak in simulations is at 0.01 GeV/tile

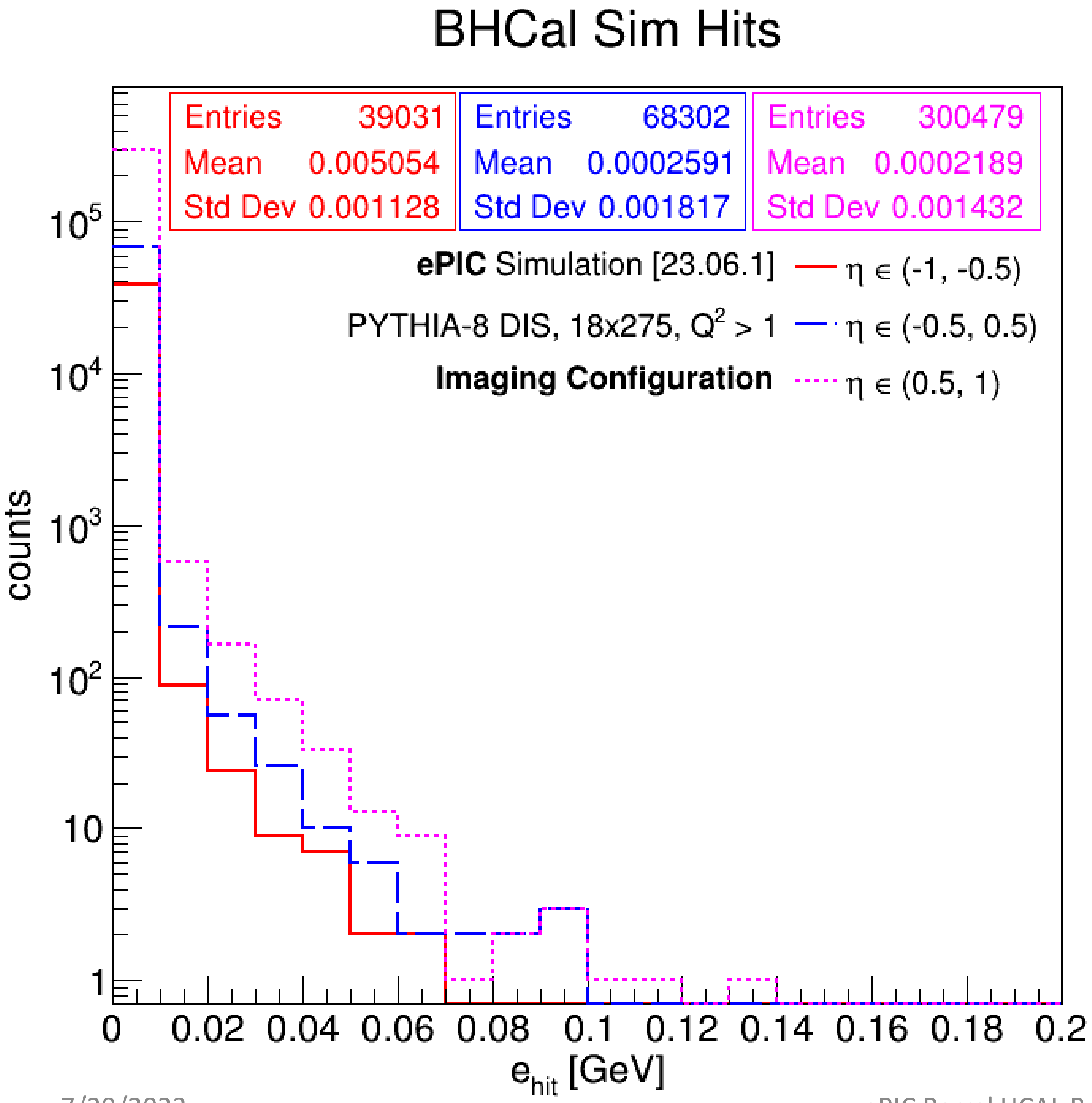
This corresponds to:

0.01 GeV * 3200 pixels/GeV * (0.32/0.25) = 41 pixels

This is a lower than the sPHENIX tower estimate using the sampling fraction (~100 pixels). Close to the lower end of the dynamic range of the H2GCROC, but still within in.

Will need to worry a lot about noise to make sure the MIP peak is not swamped. May be able to mitigate incoherent noise by adding scintillators.


BACK UP



This is the distribution of energy deposited in the scintillating tiles (*visible* energy) in an ePIC simulation of 18x275 GeV DIS events (10k events total). The regions are split in rapidity, and the higher overall energy deposition at positive rapidity is visible. (Simulation and plot courtesy of Derek Anderson, ISU.)

How does this compare to sPHENIX?
sPHENIX had a range to 50 GeV total energy in a tower (5 scintillators). Correcting for the sampling fraction and number of scintillators in a tower:

50 GeV*0.03/5 = 300 MeV

is the equivalent single scintillator slat energy for sPHENIX. So, this is not all that different from the sPHENIX requirements.

sPHENIX sees ~16000 pixels per GeV of *visible* energy in the scintillator (per Jin Huang, 7/21/22 email and 2016 sPHENIX test beam).

16000 pixels/GeV/5 scintillators = 3200 pixels/GeV (ePIC)

So 0.3 GeV of *visible* energy corresponds to ~960 SiPM pixels firing. (As we know already, we are not using anything like the full range of the 40k pixels in the SiPM, so linearity issues with the SiPM should not be a concern.)

At the other end of the spectrum, a MIP muon loses about ~1GeV in traversing the HCAL from inner to outer radius. This corresponds to:

1 GeV * 0.03 * 3200 pixels/GeV = ~96 pixels/scintillator

We need a little bit of room on the lower end, so let's say 20 pixels.

So – the dynamic range in fired pixels we want in ePIC is in the range of ~20-1000 pixels.

(**TO DO** – look at the tile energy distribution for single muons to get an understanding of efficiency.)

sPHENIX used the Hamamatsu S12572-015P-02 SiPM, operated at ~10^5 gain (about 3V over breakdown, or ~68V). The terminal capacitance of the S12572-015P-02 is 320pF at V_{op}. Therefore, the junction capacitance is

$$C_J = \frac{C_T}{N_{pix}} = \frac{320pF}{40000} = 8\text{fF}$$

This gives a single pixel charge output of $Q = C_J \Delta V$ = 8fF x 3V = 24fC

ePIC plans to use the Hamamatsu S14160-3015PS SiPM, operated at ~3.6×10^5 gain (about 4V over breakdown, or ~42V). The terminal capacitance of the S14160-3015PS is 530pF at V_{op}. Therefore, the junction capacitance is

$$C_J = \frac{C_T}{N_{pix}} = \frac{530pF}{39984} = 13\text{fF}$$

This gives a single pixel charge output of $Q = C_J \Delta V$ = 13fF x 4V = 52fC

The S14160 has a 32% QE, compared to the S12572 which was 25%. So the dynamic range of fired pixels is:

20 – 1000 pixels x (0.32/0.25) = 26 - 1300

Combined with the dynamic range of fired pixels (26-1300) this means the charge range we would see is 1.3 – 68 pC. Of course, we would want more resolution in the lower range from the HGCROC ADC and then resolution at higher amplitudes from the TOT.